Dateline: 10:00 a.m., January 10, 1996, Fairbanks, Alaska
Near the campus of the University of Alaska at Fairbanks, a flatbed truck has slid off an icy road and now rests precariously at the bottom of a steep embankment. Included in the truck's cargo is a filled 1-ton liquid chlorine cylinder bound for the nearby water treatment plant. Mary Schubert, the university's safety manager, runs ALOHA in order to assess the hazard to the campus if the cylinder is damaged when the truck is hauled back onto the roadway. Her experience suggests that the most likely accidental release would be a leak from the 2-inch valve at the center of one end of the cylinder (which is lying on its side on the bed of the truck).

The current air temperature is -30°F (-34°C), but Mary expects the temperature to warm by 3 or 4 degrees during the day. Wind speed is about 6 miles per hour, the sky is clear with no inversion present, and the relative humidity is 25 percent. The cylinder is 2.5 feet in diameter and about 6.8 feet long. Mary runs two ALOHA scenarios for this release, the first at the current temperature and the second at a temperature of -26°F (-32°C), the likely air temperature by midday. ALOHA's results momentarily surprise her because the footprint plots are quite different, but she soon realizes what the model is telling her.

Running the scenarios
You can run these scenarios in ALOHA to see what Mary found (first try some of the example problems in the ALOHA manual if you wish to review how to set up and run ALOHA scenarios). To do this:

1 Indicate the location of the release by choosing Fairbanks, Alaska from the city library (choose **Location...** from the **SiteData** menu).
2 Enter January 10, 1996, as the date and 10:00 as the time (choose **Date & Time...** from the **SiteData** menu, then click **Set constant time**).
3 Choose chlorine from the chemical library (choose **Chemical...** from the **SetUp** menu).
4 Enter the weather conditions described above (choose **User Input...** from the **Atmospheric** submenu under the **SetUp** menu). If you're using ALOHA 5.1, choose stability class F (ALOHA 5.2 chooses the stability class for you). For your first scenario, enter an air temperature of -30°F. For the second scenario, change the air temperature to -26°F. Because the release is in an urban area with many trees present, choose "Urban or forest" to describe the ground roughness at the location. Enter a relative humidity value of 25 percent.
5 Choose **Tank...** from the **Source** submenu under the **SetUp** menu, then click the button representing a horizontal cylindrical tank. Enter the tank's dimensions as described above. To run both scenarios, indicate that the chlorine in the tank is liquid (click **Tank contains liquid**) and that the tank

temperature is equal to the air temperature. Indicate that the release is through a 2" diameter pipe/valve rather than a simple hole in the cylinder wall. Indicate that the leak is located 50 percent of the way to the top of the tank. When you set up the first scenario, you'll be asked to describe the puddle formed when the liquid chlorine flows out of the tank. Since you don't know the puddle and ground temperatures, set both equal to the air temperature.

6 Mary chose to use chlorine's IDLH of 10 ppm as her Level of Concern (LOC). Since the IDLH is the default LOC in ALOHA, just choose **Footprint** from the **Display** menu to see the footprint for each scenario. Remember that an ALOHA footprint represents the area within which chlorine concentrations in the air near ground level are predicted to exceed your LOC.

Mary's results
If you repeat Mary's ALOHA runs, you'll find that the footprint doubles in length when you increase the temperature by only 4°F. She used ALOHA 5.2, and found that at a temperature of -30°F, the footprint was 889 yards (813 meters) long (Figure 1). When she changed the temperature to -26°F, the footprint length increased to 1,658 yards, or 1516 meters (Figure 2). If you use ALOHA 5.1 to repeat her work, you will obtain different estimates of footprint length, but you will see the same relationship: the length approximately doubles when you increase temperature from -30°F to -26°F.
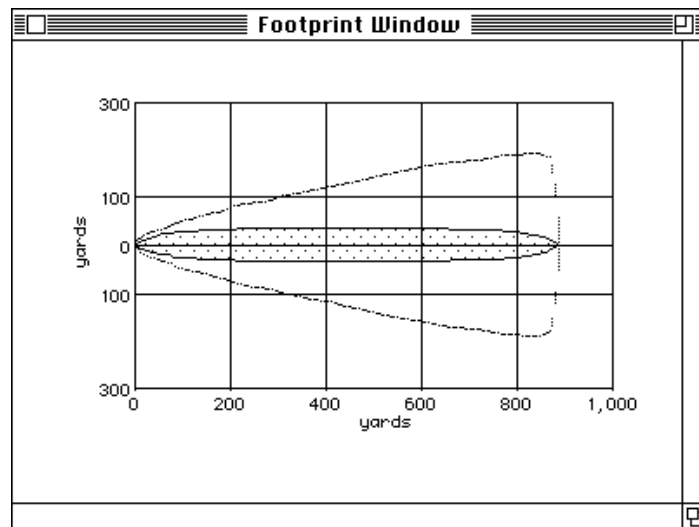

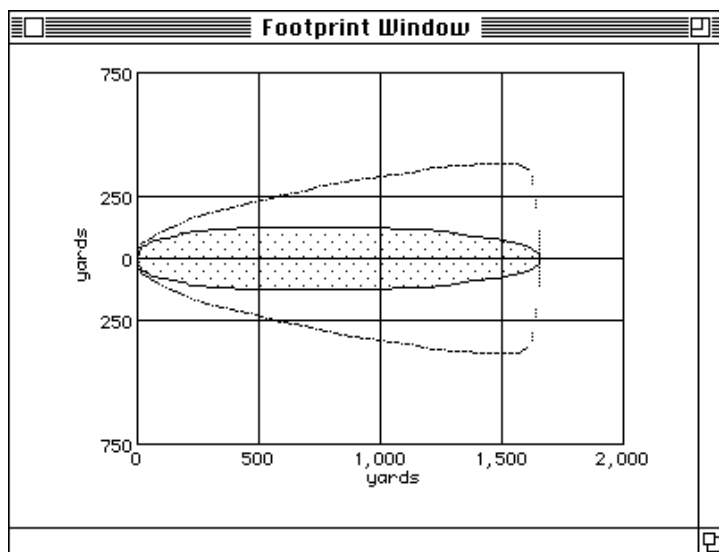Figure 1. ALOHA 5.2's footprint when air temperature is -30°F.

Figure 2. ALOHA 5.2's footprint when air temperature is -26°F.

An explanation
Mary obtained another important result: at the lower temperature, ALOHA expected the liquid chlorine to form a puddle on the ground below the leaking tank, but at the higher temperature, it did not. Why? The big difference between Mary's two scenarios is that in the first, the temperature of the air and the chlorine cylinder is just below chlorine's boiling point of -29.25°F; in the second, the temperature is above the boiling point. A liquid like chlorine will escape from a tank very differently depending on whether it is at a temperature above or below its boiling point. ALOHA alerted Mary that, so near the boiling point, tank temperature would have a big influence on her results; when she ran the lower-temperature scenario, ALOHA displayed the alert shown in Figure 3.
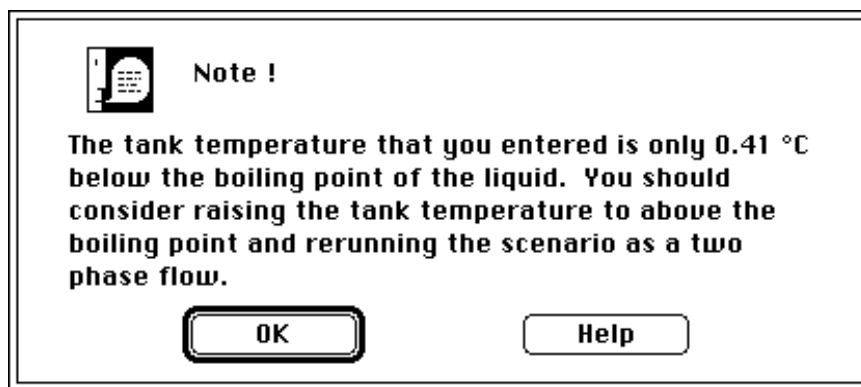

Figure 3. ALOHA 5.2 alert displayed when tank temperature is almost boiling.

Below the boiling point　　　When a chemical is at a temperature below its boiling point, it remains liquid when it is under atmospheric pressure or any higher pressure. It will drain from a punctured tank under the force of gravity, pool on

the ground, and then evaporate into the air. ALOHA estimates how quickly the liquid will flow out of the tank and how rapidly the pool will increase in volume and spread outward (when it makes these calculations, ALOHA assumes that the ground below the tank is flat); it then estimates how quickly the liquid will evaporate as vapor into the atmosphere. ALOHA uses this evaporation rate as its estimate of source strength to predict the size of the footprint.

Above the boiling point   Something very different happens when the temperature of a liquid confined in a tank rises above the boiling point. When chlorine (or any other liquid) is unconfined, so that it is under atmospheric pressure, it is a gas whenever it is above its boiling point. But up to a certain temperature called the critical temperature, chlorine – like any chemical – can be liquefied by applying higher pressures to it (above the critical temperature, a gas cannot be liquefied by increasing pressure). The chlorine in the cylinder at Fairbanks would remain a liquid if the tank temperature were to rise above the boiling point, because its vapor pressure also would rise, increasing the tank pressure. It would exert enough pressure on itself to remain liquid.

When a tank rupture or valve leak causes the pressure within a cylinder of liquefied chlorine to drop, however, the chlorine boils violently and many small gas bubbles form within the liquid. The mixture of boiling liquid and gas bubbles foams up, filling the head space within the tank with a mixture of liquid and suspended gas bubbles.

If the tank is punctured or a valve leaks at a height above the liquid level, the pressure within the tank forces a mixture of gas and liquid out through the hole or leaking valve into the atmosphere. Outside the tank, a cloud of gas and suspended liquid droplets, which are called **aerosol**, forms and begins to move downwind. If the tank is punctured at a height below the liquid level, pure liquid escapes through the hole. But as it escapes into the atmosphere, a proportion of the liquid "**flashes**" – almost instantaneously vaporizes – because of the drop in pressure it experiences in going from the tank into the air. The rest of the liquid is incorporated as aerosol into the escaping gas cloud (depending on the circumstances, some liquid also may fall to the ground). In this case, too, a mixture of gas and aerosol escapes into the atmosphere.

When a mixture of liquid and gas escapes from a ruptured tank into the air, the release is called a **two-phase flow**. The release rate can be much higher than it would be if only pressurized gas were released, in large part because liquid is much denser than gas. This effect showed up in Mary's results: ALOHA 5.2 predicted that when the temperature was above boiling – so that the chlorine escaped as a two-phase flow – the maximum release rate was about 10 times faster than when the temperature was below boiling, so that the chlorine formed an evaporating pool (Figure 4). If you're using ALOHA 5.1, you'll obtain different release rate estimates, but you'll be able to see that the rate is much higher for the two-phase scenario than for the evaporating pool scenario.
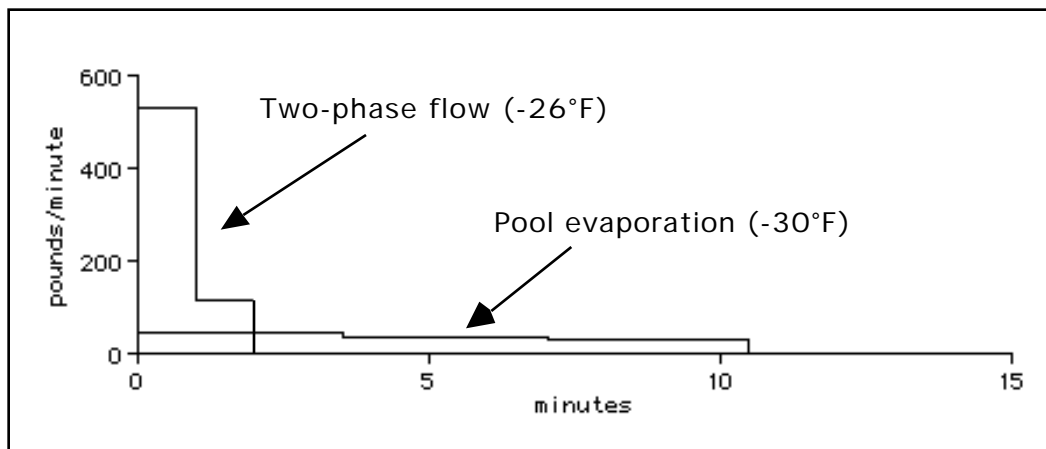
Figure 4. Source strengths predicted by ALOHA 5.2 for Mary Schubert's two-phase flow and pool evaporation scenarios.

When a chemical escapes from storage as a two-phase release, it can form a heavy gas cloud. The cloud is heavy in part because it is initially cold (when a liquid flashes or a gas expands as it leaves a pressurized tank, its temperature drops) and therefore dense, and also because it consists of a two-phase mixture. The tiny aerosol droplets mixed into the cloud act to weigh the cloud down and make it more dense, and they evaporate as they travel downwind, keeping the cloud cool.

ALOHA predicts that a chemical will escape from a tank as a two-phase mixture of gas and aerosol whenever the tank temperature exceeds the chemical's boiling point. You can check the Text Summary screen to see whether ALOHA predicts that two-phase flow has occurred. Just look for the message, "Note: the release was a two-phase flow" under the SOURCE STRENGTH INFORMATION heading (the wording of this message is a bit different in ALOHA 5.1).

ALOHA makes a conservative assumption   Whenever ALOHA expects two-phase flow to occur, it assumes that no liquid aerosol rains out of the cloud and falls to the ground. Such "rain-out" would reduce the amount of chemical in the cloud. At temperatures well above the boiling point, research results suggest that this assumption is accurate. But in cases like Mary's scenario, when the temperature is just barely above the boiling point, this assumption may be less accurate; it's likely that some of the aerosol would pool on the ground. This is an example of a conservative assumption – one more likely to lead to an overprediction of source strength and footprint length rather than an underprediction. You may wish to bear it in mind as you evaluate ALOHA results for a scenario like Mary's. But consider at the same time that it can be difficult to accurately estimate the temperature within a tank, especially during

emergency response. If the tank temperature is higher than you have guessed, it is more likely that ALOHA's assumption is accurate.

Use ALOHA with care when temperature is near boiling   Chlorine's boiling point is well below typical air temperatures, but boiling points of other common hazardous chemicals, such as hydrogen fluoride, vinyl bromide, and acetaldehyde, are within the common ambient temperature range. When you use ALOHA to respond to an accident involving one of these chemicals, be as accurate as you can when you estimate tank temperature. Your results from ALOHA can differ dramatically, depending on whether your estimate of tank temperature is above and below boiling. If you can't obtain an accurate estimate, run ALOHA at least twice, once with your highest likely tank temperature estimate, and again with your lowest likely estimate.

Two-phase flows are a particularly dangerous kind of accidental release, because two-phase mixtures form large, dense clouds that can travel far downwind. Chemical concentrations within a two-phase cloud can remain high well downwind of a release. If you suspect that a particular accident might result in a two-phase flow, be sure to check ALOHA's Text Summary window to see whether the model predicts that a two-phase flow is likely.